INJURY RISK FUNCTIONS FOR INDIVIDUAL CAR MODELS

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ABSTRACT

The relation between impact severity and risk of injury is a fundamental issue in terms of comparing vehicles and occupant protection systems. Normally, such risk functions would have to be based on reconstruction of crashes, limiting the possibility to generate risk functions down to individual car models. In this study, an alternative way to derive risk functions was developed and used. In the present method, risk functions were derived using matched pairs of crashes, varying mass relations in a controlled way, and generating risk versus relative change of velocity. The data used was police reported crashes in Sweden during 1994-2000. The results show, that there are major differences in injury risk functions between individual car models. The results are of major importance for the development of car model safety rating and for the evaluation of new car safety technology. The method is also of importance in understanding possible scenarios of sub optimisation. In the development of vehicles there is a risk of concentration on certain crash severities instead of looking at the overall performance.

BACKGROUND

The risk of an injury can be described as a dose-response function, where the dose is the amount and type of mechanical force acting on a human. In car impacts it is often referred to as the impact severity. Especially in frontal or rear-end impacts, this exposure dose is often given as the change of velocity that the vehicle undergoes in a crash.

The knowledge on the dose response functions is fundamental in the understanding of how humans are injured, as well as a basis for prevention in terms of restraints, etc. The knowledge also serves as important input to crash tests and mathematical simulations as well as for setting injury criteria for human substitutes. Furthermore, injury risk functions from real-world crashes can be used to validate transfer functions from laboratory data to predict real-life outcome.

There are different ways to establish injury risk functions versus impact severity. The most common way is to relate measured or calculated parameters describing impact severity to injury risk. Traditionally, impact severity has been estimated by reconstruction of impacts. To date reconstructions of vehicle collisions are most often based on retrospective studies where static measurements of different parameters describing the circumstances in the collision are included. Vehicle deformations have usually been used as input for reconstruction programs, as for example Crash3, to calculate EBS or EES (Crash3 Technical Manual, 1986; Zeidler et. al., 1985). If in a two-car collision the EES of both vehicles is known, the change of velocity for the involved vehicles can be calculated. Over the last few years, crash recorders have been introduced and used (Salomonsson and Koch, 1992; Norin, 1995; Kullgren, 1998).

Calculations of change of velocity with reconstruction programs have been shown to generate substantial measurement errors (Lenard et. al., 1998; Nolan, et. al., 1998; Stucki and Fessahaie, 1998), which are very complicated to handle in analyses of risk functions. The number and magnitude of errors have been found to be of an order that seriously influences the conclusions drawn from risk functions (Kullgren and Lie, 1998).

Studies have been presented showing injury risk versus measured change of velocity by using on-board crash recorders (Kullgren, 1998; Kullgren et. al., 1999), see Figure 1.
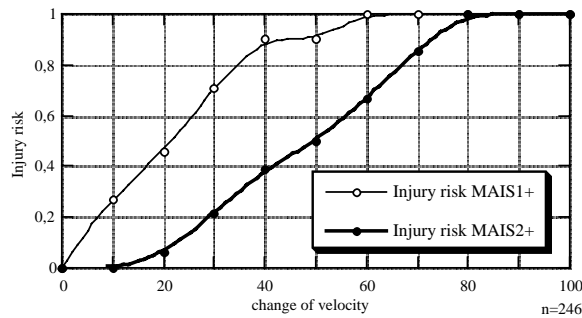
Figure 1. Injury risk versus change of velocity, MAIS1+ and MAIS2+. (from Kullgren et. al., 1999)

An alternative way of calculating injury risk is by induced methods, for example by using paired comparison technique (Krafft et al. 2000). Such methods would have the advantage of being used on large samples of readily available accident data.

In this study, an alternative to accident reconstruction to generate risk functions for individual car models is proposed.

The aim of the study was to:

- Present an alternative to the derivation of injury risk functions based on paired comparisons, and

- To apply the method on accident data material in order to produce risk functions for some individual car models.

METHOD

Basically, the change of velocity can be calculated from the law of the conservation of momentum, where:

$$\text{Delta } V_1 = V_{rel}(M_2 / (M_1 + M_2)), \qquad \text{(Eq. 1.)}$$

where V_{rel} is the relative velocity and M_1 and M_2 the masses of the two vehicles colliding.

This relation is true even if the two vehicles involved do not have a common velocity after the impact. If the masses are equal, both vehicles will undergo the same change of velocity. This method uses this fact, and that any deviation in mass can be

transferred to differences in change of velocity, as long as the individual masses are known (Figure 2). The method cannot generate absolute figures, only risks relative to each other.

Instead of generating new risk functions, the method uses the change on the exposure distributions and the resulting change in risk.
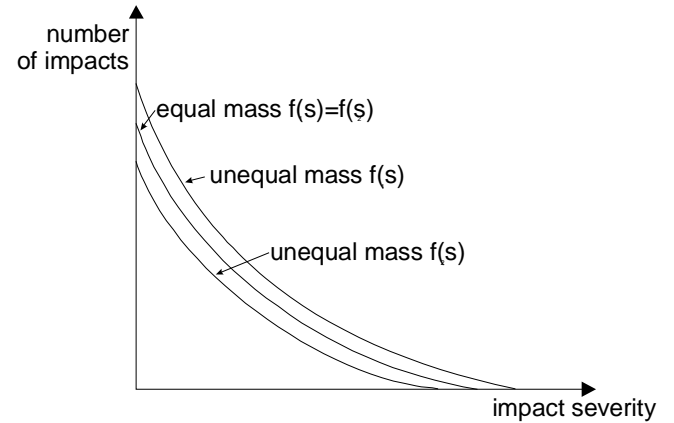
Figure 2. Impact severity (delta-V) for cars in matching crashes for equal mass: $f_1(s) = f_2(s)$ and unequal mass: $f_1(s) \neq f_2(s)$ where car 1 is of less mass than car 2

The basis for the statistical method is the paired comparison technique, where two car accidents are used to create relative risks. The method was initially developed by Evans (1986), but has been developed further for car-to-car collisions by Hägg et. al. (1992).

The assumption for the method is that the risk of injury is a continuous function of change of velocity. This assumption might conflict with safety features such as airbags that might generate a step-function. This would have to be further investigated. Another assumption is that injuries in one car are independent from the injuries in the other car, given a certain accident severity.

For a given change of velocity the risk of an injury is p_1 and p_2 in the two cars, respectively. For that change of velocity, the outcome of the accident is therefore:

Table 1.

Probabilities of Injury to Driver in Car 1 and 2 in a Segment of Impact Severity

		Driver of Car 2		
		driver injured	driver not injured	Total
Driver of Car 1	driver injured	$n_i P_{1i} P_{2i}$	$n_i P_{1i} (1-P_{2i})$	$n_i P_{1i} P_{2i} + n_i P_{1i} (1-P_{2i}) = n_i P_{1i}$
	driver not injured	$n_i (1-P_{1i}) P_{2i}$	$n_i (1-P_{1i}) (1-P_{2i})$	
	Total	$n_i P_{1i} P_{2i} + n_i (1-P_{1i}) P_{2i} = n_i P_{2i}$		

Summing over all change of velocities, the outcome will be:

Table 2.

Summarised Probabilities of Injury to Driver in Car 1 and 2

		Driver of Car 2		Total
		driver injured	driver not injured	
Driver of Car 1	driver injured	$\sum_{i=1}^{m} n_i P_{1i} P_{2i} = x_1$	$\sum_{i=1}^{m} n_i P_{1i} (1-P_{2i}) = x_2$	$\sum_{i=1}^{m} n_i P_{1i} P_{2i} + n_i P_{1i} (1-P_{2i}) = n P_1$
	driver not injured	$\sum_{i=1}^{m} n_i (1-P_{1i}) P_{2i} = x_3$	$\sum_{i=1}^{m} n_i (1-P_{1i}) (1-P_{2i}) = x_4$	
	Total	$\sum_{i=1}^{m} n_i P_{1i} P_{2i} + n_i (1-P_{1i}) P_{2i} = n P_2$		

The relative risk of an injury, for vehicle 1 to 2, given a certain change of velocity distribution is therefore:

$$R = (x_1 + x_2) / (x_1 + x_3) = \frac{\sum n_i P_{1i}}{\sum n_i P_{2i}} =$$

$$\frac{\sum n_i P_{1i} P_{2i} + \sum n_i P_{1i} (1 - P_{2i})}{\sum n_i P_{1i} P_{2i} + \sum n_i (1 - P_{1i}) P_{2i}} \quad \text{(Eq. 2.)}$$

The method is unbiased for any combination where the vehicles are of the same weight; i.e. the mass ratio is 1. If the vehicles are of different weights, the two vehicles will undergo different changes of velocity, which will have to be compensated for. Generally, we can introduce any component, K, that will affect the risk of injury in either, or both of the vehicles. If we let K_1 denote this factor in vehicle 1, and K_2 in vehicle 2, this will lead to:

(1) $\quad n_i P_{1i} P_{2i} K_1 K_2 / n_i P_{2i} K_2 + \ldots + n_i P_{1i} P_{2i}$

$$K_1 K_2 / n_i P_{2i} K_2 = \sum_{i=1}^{m} n_i P_{1i} P_{2i} K_1 / \sum_{i=1}^{m} n_i P_{2i}$$

$$= K_1 \sum_{i=1}^{m} n_i P_{1i} P_{2i} / \sum_{i=1}^{m} n_i P_{2i} \qquad \text{(Eq. 3.)}$$

To solve the equation, cars of different weights will be used, where the weights are known. K will therefore denote the role of change of velocity, and could be a constant, or a function of, say, change of velocity.

(1) is estimated by $K_1 (X_1 / (X_1 + X_3))$ (2) and, K_1

$$= \frac{\left(X_1/(X_1 + X_3)\right)_{m_b}}{\left(X_1/(X_1 + X_3)\right)_{m_a}} \quad \text{(3) where,} \qquad \text{(Eq. 4.)}$$

m_a and m_b are mass relations in the matched pairs. These mass relations are transformed to relative change of velocity by

$$\frac{m_b}{m_a} = \left(m_2 \Big/ (m_1 + m_2)\right)_b \Big/ \left(m_2 \Big/ (m_1 + m_2)\right)_a \text{(Eq.5.)}$$

The analytical functions chosen to describe the risk functions have been applied simply using either a linear function or a power function. This issue would have to be further investigated using more advanced material.

It is obvious, that while the importance of a marginal change of velocity will be calculated, as well as parts of the risk function, absolute values cannot be given. If this is to be done, a key value must be brought into the equation.

MATERIAL

The material used was police reported two car crashes from Sweden (1994-2000). Injuries were classified by the police into severity in three classes. The data used in the analysis were all police reported crashes with injuries to at least one driver.

Police reports are known to have some problems with quality. While using only a few variables from the police records, the main quality issue lies with the under-reporting, and the lack of in-depth medical data. Under reporting of crashes would not lead to bias in the risk functions, but under-reporting of injuries in a crash used in the analysis

would bias the outcome. To which extent that is an issue in the current analysis is not known and would have to be further investigated.

For all crashes the kerb weight of the case vehicle and opponent vehicle is known.

The vehicles studied were a set of common models on the Swedish roads. Some car models were grouped to obtain larger data sets. In all four vehicle models were studied.

As opponent vehicles all other cars were used. These were group into groups spanning over 100, 200 and 300kg of kerb weight.

Only groups containing at least 25 cases (x_1+x_3) were analysed.

In all 9946 crashes containing any injury were studied. Of these crashes 861 contained a severely or fatally injured driver.

RESULTS

The results are subdivided into analysis of all injuries and injuries classified as serious or fatal. In fig 1, the risk function for severe or fatal injuries for just one car type, Volvo 200/700/900 is shown. The rationale for grouping several models together, is that it has been earlier shown, that these models do not differ to any major degree in injury risk. It is also a way to, while data is limited, to generate a stabile risk function for comparison with other car models.
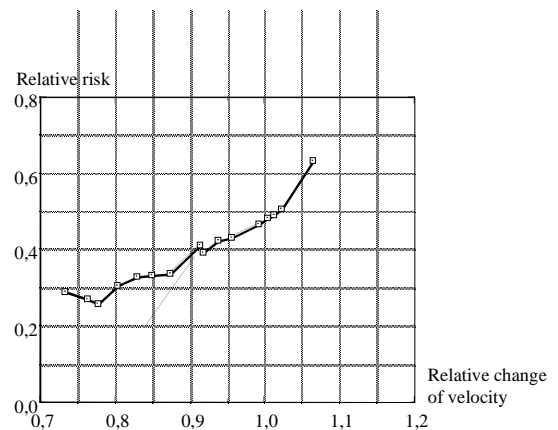

Figure 1. The relative risk for severe or fatal injury in Volvo 200/700/900 cars

It can be seen from fig 1, that the risk of injury over an interval of change of velocity of 75% of average change of velocity for serious injuries, up to almost

110% of average change of velocity, the risk of a serious of fatal injury is increased more than two fold. While the relationship between change of velocity and risk of a serious or fatal injury may look linear, it is still only a part of the whole picture, which might fit into a different type of analytical function.

It can also be seen in fig 1, that the relationship is stabile and seems to fulfil the assumption of a continuous function.
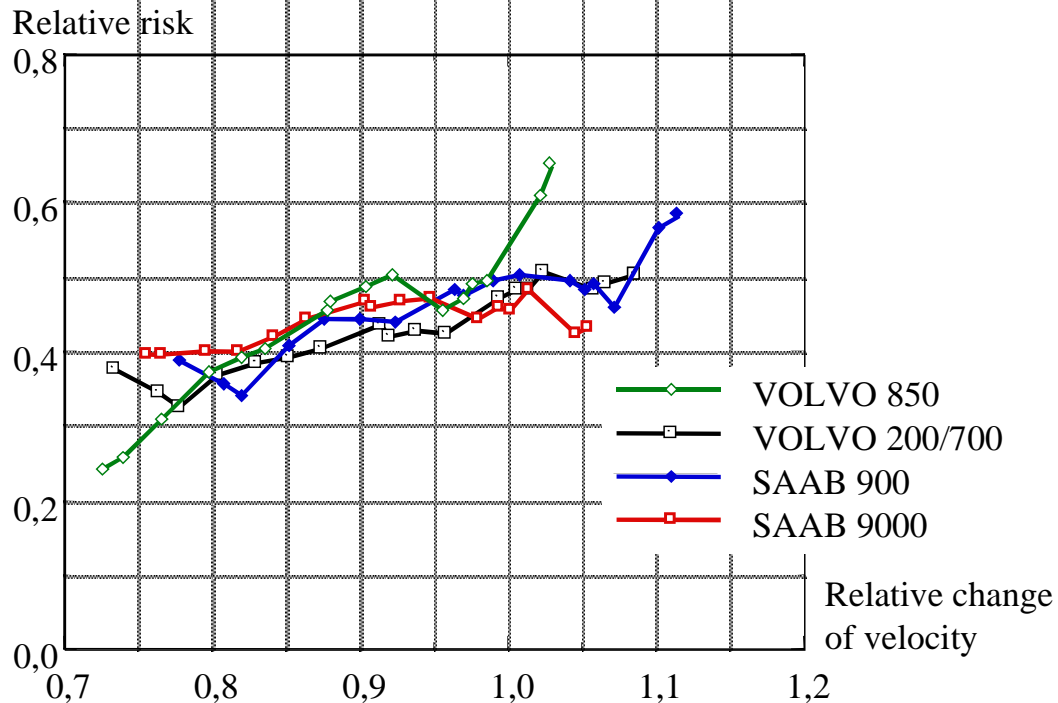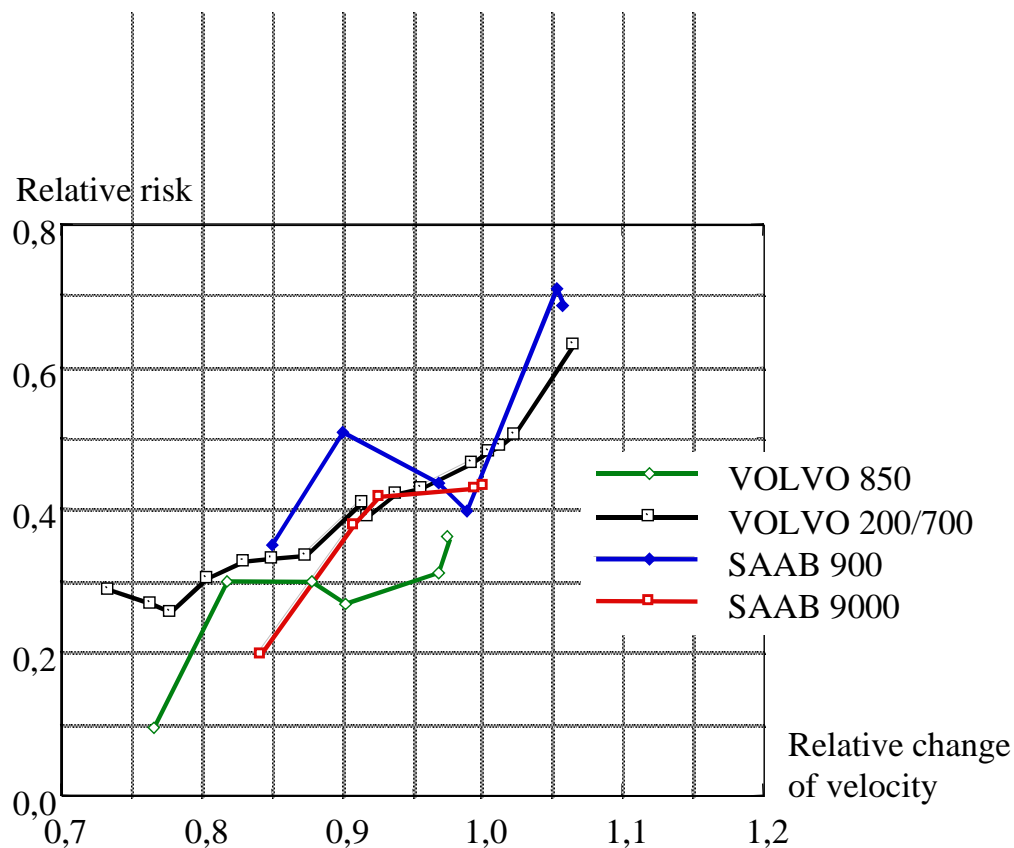
Relative risk

Figure 2. The relative risk for any injury

In fig 2, all injuries for four car models, are shown. It can be calculated, that the risk of injury is increased by only approximately 60% of the range from 76% to 107% of average change of velocity, which is a large difference to the serious and fatal injuries. This seem to suggest that minor injuries are far less sensitive to change of velocity, or more likely, that the figure shows a cut of the relationship where the risks are closer to 1.

Fig 2 also shows that there are only minor differences between individual car models, although Volvo 850/70 shows an increased risk for injury close to the average change of velocity.

Figure 3. The relative risk for severe and fatal injury

Fig 3 shows the results for the four individual car models for serious and fatal injuries. There seems to be major and consistent differences between some models. Volvo 850/70 has a lower injury risk than the rest more or less over the entire range of change of velocities, indicating that the positive results for this car is generated by better safety levels both for lower and higher changes of velocity.

Except for one observation, Saab 900 produces worse figures over the entire range, while Saab 9000 has lower risk levels for the lower spectrum of crash severities.

DISCUSSION

This study shows that it is possible to generate risk functions without accident reconstruction, although absolute functions in terms of figures on change of velocity cannot be given. This gives us a method to validate, and to modify, risk functions derived by other methods. These methods, if they are based on reconstruction, are subject to errors in a magnitude that can seriously affect the calculated relationship between accident severity and risk of injury. Kullgren and Lie (1998) have shown that random errors in the impact severity term in the order of

15% or greater can affect the risk functions. Such errors are often larger. Serious consequences can be foreseen by such errors in the field of crash protection. It is important to understand that while it is quite common to generate accumulated proportions of injuries related to change of velocity, the current method tries to actually generate true risk functions, which is the risk of injury for a certain mechanical dose (change of velocity).

The method proposed could also be used to validate risk functions derived with methods based on reconstruction. While reconstruction normally would have to be based on limited accident data, mass data can be used to derive risk functions with the present method. It should therefore be possible to look at more or less any injury, even if it is rare. The method can also be used for studying the consequences of vehicle fleet down weighting on numbers of fatalities and injuries.

However, crash pulse recorders make it possible to relate crash pulse characteristics, as for example mean and peak acceleration, to injury risk, which is not possible if impact severity is calculated with traditional accident reconstruction techniques. Figure 4 shows an example of injury risk versus mean acceleration based on recorded crash pulses in real-world impacts (from Kullgren et. al., 1999).
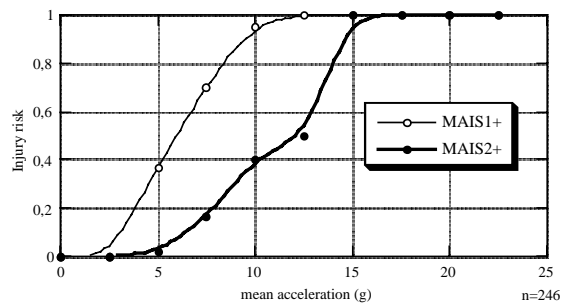
Figure 4. Injury risk versus mean acceleration MAIS1+ and MAIS2+ (from Kullgren et. al., 1999)

The method presented in this paper is probably sensitive to errors, or approximations of vehicle weight. In this study, the service weight of the car was used, while this is not necessarily the weight of the car at the time of impact. Loading of passengers and cargo will have a certain impact on the figures, as well as modifications to cars.

The results from the analysis show large and consistent differences between individual car models. In particular, the results for the Volvo 850/70 shows, that while this car has a generally lower risk of injury for the driver, the risk is lower over the whole measurable spectrum of impact severities. This indicates that the good results have not been achieved by sub optimisation in that the vehicle generates higher injury risks for lower impact severities to get good results for higher severities.

While it was possible to generate risk functions for some common car models in Sweden, it is highly unlikely that many cars could be studied in terms of risk functions. This raises the need for pooling data over many countries. This might not be as complicated as it seems first, as the method presented does not rely on many variables. It should therefore be possible to merge data from a number of countries in the future.

CONCLUSIONS

- Individual risk functions describing the relation between relative change of velocity and risk of injury can be calculated.

- There are major and consistent differences in risk functions for individual car models when four cars are compared.

REFERENCES

"CRASH3 Technical Manual", Accident Investigation Division, NCSA, NHTSA, 1986.

Evans L. Double paired comparison – a new method to determine how occupant characteristics affect fatality risk in traffic crashes. Accident Analysis and Prevention, Vol 18 No 3, pp 217-227, 1986.

Hägg A, v Koch M, Kullgren A, Lie A, Nygren Å, Tingvall C, Folksam Car Model Safety Rating 1991-92, Folksam Research 10660, Stockholm, 1992.

Krafft M, Kullgren A, Les M, Lie A and Tingvall C. Injury as a function of change of velocity, an alternative method to derive risk functions. In proceeding from IMechE, Vehicle Safety 2000. London 2000, pp 263-273.

Kullgren, A. Lie, A. Vehicle Collision Accident Data - Validity and Reliability, Journal of Traffic Medicine, vol. 26, no. 3-4, 1998.

Kullgren A. Validity and reliability of vehicle collision data: Crash pulse recorders for impact severity and injury risk assessments in real-life frontal impacts. Thesis for the degree of Doctor in Medical Science, Folksam, 106 60 Stockholm, 1998.

Kullgren A, Tingvall C, Ydenius A. Experiences of Crash Pulse Recorders in Analyses of Real-World Collisions. Presented at the Crash 2000 Conf. in Canberra, 1999.

Lenard J, Hurley B, Thomas P. The Accuracy of Crash3 for Calculating Collision Severity in Modern European Cars, Proc. 16th Int. Techn. Conf. on ESV, Paper No. 98-S6-O-08, Windsor, Canada, 1998.

Nolan J M, Preuss C A, Jones S L, O'Neill B. An Update on the Relationships Between Computed Delta Vs and Impact Speed for Offset Crash Tests. Proc. 16th Int. Techn. Conf. on ESV, Winsor, Canada, 1998.

Norin H. Evaluating the Crash Safety Level of Components in Cars. Thesis for the degree of Doctor in Philosophy, ISBN 91-628-1649-7, Karolinska Institutet, Stockholm, 1995.

Salomonsson O, Kock M. Crash recorder for safety system studies and as a consumers product. SAE SP 852 Fontal crash safe technologies for the 90´s, Warrendale, 1991.

Stucki S L, Fessahaie O. Comparison of Measured Velocity Change in Frontal Crash Tests to NASS Computed Velocity Change, Proc. SAE Conf., Paper 980649, 1998.

Zeidler F, Schreier H-H, Stadelmann R. Accident Research and Accident Reconstruction by the EES-Accident Reconstruction Method. SAE-paper 850256, Warrendale, 1985.